

# Aloha Partners, L.P.

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August 12, 2008

Commissioner Jonathan S. Adelstein  
Federal Communications Commission  
445 12th Street SW  
Washington, DC 20554

**RE: ET Docket No. 04-186**

Dear Commissioner Adelstein:

I enjoyed seeing you again and having the opportunity to discuss the benefits of licensing and auctioning the White Space spectrum. Aloha Partners believes that the benefits of licensing and auctions far outweigh any potential drawbacks. I have attached several charts which support the points we discussed last week.

One of the points that you were particularly interested in was our data on the current utilization of licensed versus unlicensed spectrum. You asked that I send you some additional information that supports my point. The first chart that is attached summarizes the National Science Foundation study of spectrum utilization in 7 separate locations ranging from New York City, to Chicago, to suburban Virginia to rural West Virginia. The results are very consistent: **Licensed spectrum is utilized at least twice as much as unlicensed spectrum.** In our chart we showed the licensed versus unlicensed spectrum percent utilization in two bands: the original Cellular frequencies (806-902MHz) versus the original unlicensed ISM frequencies (902-928MHz). We also compared the PCS licensed frequencies (1710-1990MHz) to the unlicensed PCS frequencies (2390-2560MHz). In the original 6 locations, licensed Cellular frequencies (850MHz) were used 24% of the time versus 2% for unlicensed ISM frequencies (900MHz). Licensed PCS frequencies were used 14% of the time versus 6% for unlicensed PCS frequencies. Licensed spectrum was consistently used 2 to 10 times as much as unlicensed spectrum in every location.

I have also included a copy of the National Science Study Spectrum Occupancy Measurements Project Summary which will give you the details for all spectrum blocks.

Please give me a call if you have any additional questions at 401-458-1901.

Sincerely,

\_\_\_\_\_/s/  
Charles Townsend  
President  
Aloha Partners, L.P.

# National Science Foundation Spectrum Utilization Analysis

<u>Name</u>	<u>location</u>	<u>Licensed</u> <u>(806-902)</u>	<u>Unlicensed</u> <u>(902-928)</u>	<u>Licensed</u> <u>(1850-1990)</u>	<u>Unlicensed</u> <u>(2390-2500)</u>
Riverbend Park	Great Falls Virginia	14.3%	-	-	-
Tysons Corner	Suburban Virginia	41.2%	3.9%	12.7%	-
NSF Roof	Arlington Virginia	46.3%	8.7%	27.1%	12.4%
New York Penn Station	New York City	46.3%	22.9%	33.8%	14.5%
Nat'l Radio Astronomy	Green Bank West VA	-	-	-	-
S.S.C. Roof	Vienna Virginia	40.0%	1.1%	19.3%	25.7%
6 Location Average	-	23.7%	2.4%	13.9%	6.4%
IIT Lab	Chicago, IL	54.8%	9.3%	42.8%	29.1%

# White Space Auction Revenue Estimates

<u>Protected Channels</u>	<u>Aloha Partners Est.</u>	<u>Brattle Group Est.</u>
<b>Co Channel Only</b>	<b>\$15 Billion</b>	<b>\$25 Billion</b>
<b>Co &amp; Adjacent Channels</b>	<b>\$8 Billion</b>	<b>\$12 Billion</b>

# White Space

## Clear Spectrum Estimates

### Minimum Bandwidth of White Space\*

<u>MTA</u>	<u>Co - Channel Only</u>	<u>Co &amp; Adjacent Channel</u>	<u>Difference</u>
New York	66 MHz	0 MHz	-66 MHz
Los Angeles	60 MHz	6 MHz	-54 MHz
Chicago	114 MHz	18 MHz	-96 MHz
San Francisco	72 MHz	18 MHz	-54 MHz
Dallas- Fort Worth	132 MHz	18 MHz	-116 MHz
Top 5 Wtg. Average	66 MHz	10 MHz	-56 MHz
6-10 Wtg. Average	115 MHz	25 MHz	-90 MHz
11-30 Wtg. Average	140 MHz	40 MHz	-100 MHz
Rural Wtg. Average	170 MHz	60 MHz	-110 MHz
<b>U.S. Average</b>	<b>120 MHz</b>	<b>30 MHz</b>	<b>-90 MHz</b>

\*Note: Minimum MHz/MTA  
based on Brattle Group Study

# White Space

## Rural Coverage Comparison

	<u>Power Level</u>	<u>Cell Radius</u>	<u>Square Miles Covered</u>	<u># Cells per 10,000 Sq. Mi.</u>
<u>Licensed Spectrum</u>	1 kW	30 Miles	2825 Sq. Mi.	<b>3.5 Cells</b>
<u>Unlicensed Spectrum</u>	1 Watt	4 Miles	50 Sq. Mi.	<b>200 Cells</b>

# Unlicensed Wi-Fi Failures

<u>City</u>	<u>Provider</u>	<u>Status</u>
Philadelphia	Earthlink	Shut Down
Portland	MetroFi	Shut Down
Sunnyvale	MetroFi	Shut Down
Milpitas	MetroFi	Shut Down
Cupertino	MetroFi	Shut Down
San Jose	MetroFi	Shut Down
Santa Clara	MetroFi	Shut Down
Foster City	MetroFi	Shut Down
Concord	MetroFi	Shut Down
San Francisco	Earthlink	Discontinued
New Orleans	Earthlink	Discontinued
Toronto	Earthlink	Discontinued

## NSF Spectrum Occupancy Measurements Project Summary



**Published August 15, 2005**

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**Subcontract No. FY2004-013**  
**The University of Kansas Center for Research, Inc.**  
**Spectrum Occupancy Measurements and Pre-Selector Development**  
**National Radio Research Testbed (NRNRT)**  
**National Science Foundation (NSF) Award Number: ANI-0335272**

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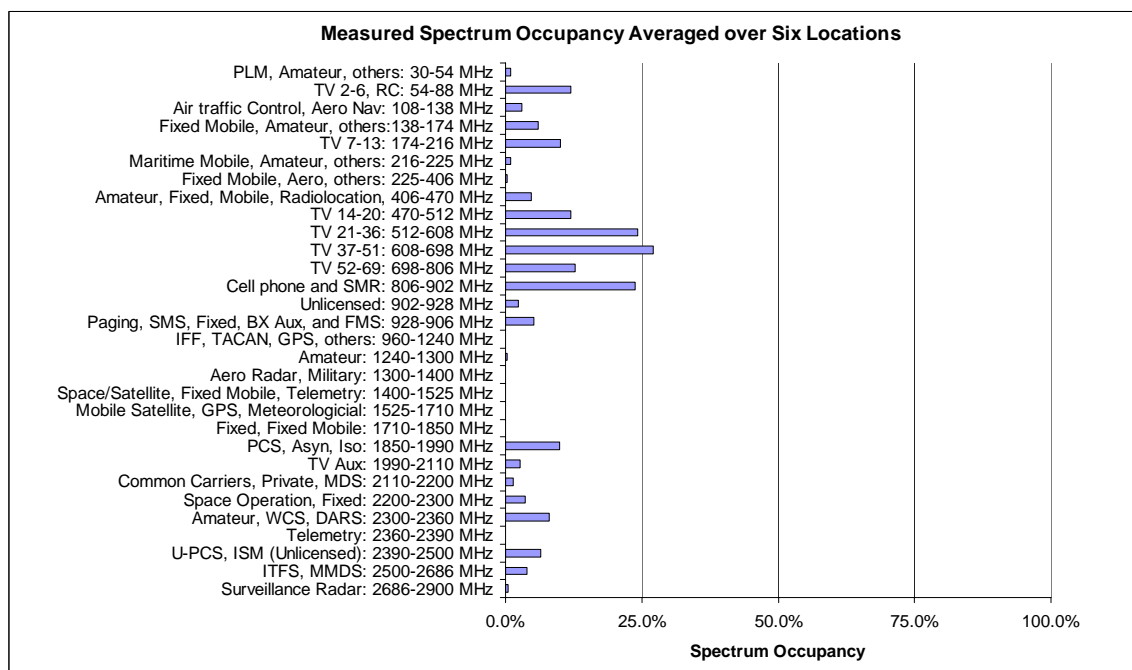
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## 1. Introduction

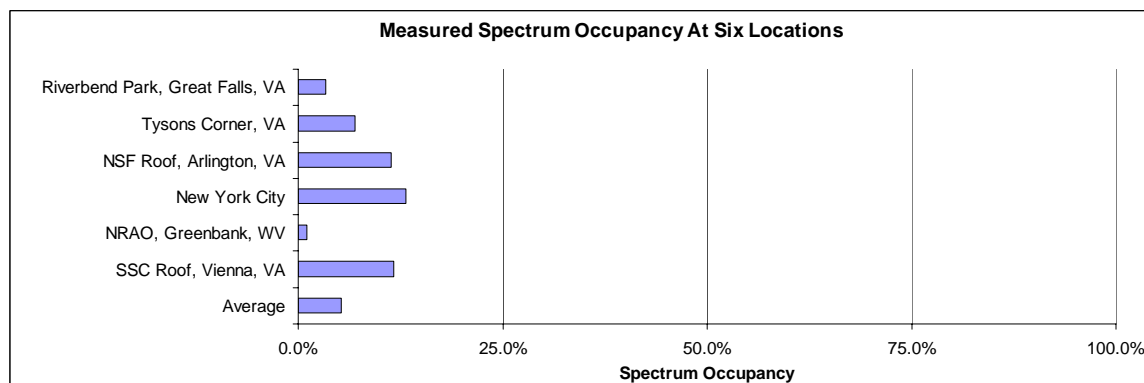
### 1.1 Summary

This document describes spectrum occupancy measurement project performed by Shared Spectrum Company from January 2004 until August 2005. The project consisted of building a high dynamic range spectrum measurement system, a data collection and processing system and conducting spectrum occupancy measurements at six locations. The results of these measurements are described in detail in six separate reports.

The goal of this study was to determine the spectrum occupancy in each band at multiple locations. The bar graphs in Figure 8 and Figure 9 below provide the average of the occupancy in each band and at each location. The average occupancy over all of the locations is 5.2%. The maximum occupancy is 13.1% (New York City) and the minimum occupancy is at the National Radio Astronomy Observatory (1%). These low occupancy levels show that there is significant spectrum for a Dynamic Spectrum Sharing Radio (DSS) to provide service. In rural areas, there is enough unused spectrum for a DSS Radio to provide ten times the capacity of all existing wireless devices together.



**Figure 1 Spectrum occupancy in each band averaged over six locations.**



**Figure 2 Spectrum occupancy at each location.**

Table 3 shows a summary of the occupancy from all six locations. Table 4, Table 5, Table 6, Table 7, Table 8, and Table 9 provide the occupancy in each band at each location. The average occupancy over all of the locations is 5.2%. The maximum occupancy is 13.1% (New York City) and the minimum occupancy is at the National Radio Astronomy Observatory (1%).

These low occupancy levels show that there is significant spectrum for a Dynamic Spectrum Sharing Radio (DSS) to provide service. In rural areas, there is enough unused spectrum for a DSS Radio to provide ten times the capacity of all existing wireless devices together.

### 1.2 Report Organization

This report is organized into six sections, as follows:

- Section 1 Introduction
- Section 2 Description of the Project Goals
- Section 3 Measurement Locations
- Section 4 Description of the Six Measurement Reports
- Section 5 Description of the Data Files
- Section 6 Conclusions
- Section 7 Suggested Follow-On Research

### 1.3 The National Radio Network Research Testbed (NRNRT)

Measurements contained in this report are part of the National Radio Network Research Testbed (NRNRT) project.<sup>1</sup> The NRNRT is a National Science Foundation (NSF) project that supports research and development of new radio devices, services, and architectures, providing a valuable facility for use by the research and development community in testing and evaluating their systems.

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<sup>1</sup> Electronic copies of the data provided in this report may be requested from NRNRT by contacting Professor Gary Minden, University of Kansas, Information and Telecommunication Technology Center, Center for Research, Inc., (email: [gminden@itc.ku.edu](mailto:gminden@itc.ku.edu); tel: 785-864-4834), or Dr. Mark McHenry, Shared Spectrum Company, (email: [mmchenry@shedspectrum.com](mailto:mmchenry@shedspectrum.com); tel: 703-761-2818 x-103)

The NNRNT consists of:

- (1) a field measurement and evaluation system for long-term radio frequency data collection, and an experimental facility for testing and evaluation of new radios;
- (2) an accurate emulation/simulation system that incorporates long-term field measurement, for use in evaluating new wireless network architectures, policies, and network protocols; and
- (3) innovative experimentation with wireless networks that integrate analysis, emulation/simulation, and field measurements.

## 2. Project Goals

### 2.1 Current Spectrum Use

The need to assure access to radio spectrum is at a crossroads. More and more technological alternatives are becoming available and demand from both public and private sectors is increasing very rapidly, if not exponentially. Increasingly, there is recognition that the root of the problem is that most of the spectrum is actually unused, and the present system of spectral regulation is grossly inefficient. Current spectral regulation is based upon the premise that slices of the spectrum, representing uses within specified upper and lower frequency bounds, must be treated as exclusive domains of single entities – who are the recipients of exclusive licenses to use specific frequency bands.

### 2.2 Changes in Regulatory Policy Related to Dynamic Spectrum Sharing

The FCC and NTIA are preparing to make rulings on the use of cognitive radio and dynamic spectrum sharing. Below are the open FCC dockets related to dynamic spectrum sharing:

- Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band, ET Docket No. 02-380
- Cognitive Radio Technologies Proceeding (CRTP), ET Docket No. 03-108
- Secondary Markets Initiative Second Report and Order, Order on Reconsideration, and Second Further Notice of Proposed Rulemaking (FCC 04-167)
- Unlicensed Operation in the TV Broadcast Bands, Docket No. 04-186
- Establishment of an Interference Temperature Metric to Quantify and Manage Interference and To Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands, ET Docket No. 03-237

There have been few spectrum occupancy measurements that cover multiple bands that provide insight on the applicability of dynamic spectrum sharing to the above rule changes.

### 2.3 Dynamic Spectrum Sharing Technology Development

The U.S. Government is investing significant research and development funding to develop spectrum sharing technology. Example programs include the DARPA XG Program and the NSF NeTS-Pro-WiN Program. These investments may be wasted unless they address the true spectrum use situation. It is critical to immediately conduct the spectrum measurement and analysis tasks described here to insure that the government's R&D investments target the correct technical problems.

### 2.4 Importance of Spectrum Measurements

Spectrum measurements are critical to government policy makers and to NSF (and other) researchers in the development of new spectrum access technologies. Specifically, spectrum occupancy studies identify what spectrum bands have low or no active utilization (and thus may be appropriate for spectrum sharing). They provide information on the signal characteristics within these bands, which is needed to design spectrum sharing algorithms. The most important use of the data is to convince senior US government officials that RF spectrum is being used

very inefficiently, and that they should make R&D investments and policy changes to support the development of dynamic spectrum sharing radios.

What is needed from spectrum measurements is a band-by-band analysis of the:

- Spectrum occupancy (peak and average)
- Detected signal parameters (transmission gaps statistics, transmitter mobility, number of transmitters, the signal bandwidths, and other parameters)
- FCC/NTIA rules to determine reasons why signals were not detected (i.e. not present, very low duty cycle, or too weak to detect)

This information needs to be collected over a wide range of locations to assess the variations of spectrum usage in several environments that have different spectrum users present and population densities (urban, suburban, and rural). The results from the different measurements must be consistently analyzed and plotted because of the complex nature of the spectrum use problem and because of the contentious points of view related to spectrum issues.

There have been several previous broadband spectrum surveys<sup>2,3,4</sup>, but they did not provide temporal spectrum use information and could not be used to provide spectrum white-space estimates.

### 2.5 Specific Project Goals

The project goal was to measure the spectrum occupancy in all bands 30 MHz to 3,000 MHz. This provides information on:

- What bands have low utilization,
- How the spectrum is being used (what types of equipment, where, when, mobile or fixed, ...),
- The existing user's equipment parameters (signal bandwidth, modulation, power levels, etc),
- The spectrum occupancy gap width and duration statistics,
- The number of transmitters in each band, and
- The background noise level.

These parameters are critical to develop cognitive radio algorithms related to dynamic spectrum sharing. Some of the above parameters come directly from the spectrum data. Other parameters need to be interpreted using models and hypothesis, which is an ongoing investigating and is not included in this project.

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<sup>2</sup> "Broadband Spectrum Survey at Denver, Colorado" Frank H. Sanders, Vince S. Lawrence, NTIA Report 95-321, September, 1995.

<sup>3</sup> "Broadband Spectrum Survey at San Francisco, California", Frank H. Sanders, Bradley J. Ramsey, Vincent S. Lawrence, NTIA Report 99-367, May-June 1995.

<sup>4</sup> "Broadband Spectrum Survey at San Diego, California", Frank H. Sanders, Bradley J. Ramsey, Vincent S. Lawrence, NTIA Report 97-34, 1995.

### 3. Measurement Locations

Table 1 shows the locations of the measurements in this project. The locations include outdoor urban and rural locations, and an indoor location. Most of the locations were highly elevated and had excellent line-of-sight to the surround area (thus, maximizing the detection probability).

**Table 1 Measurement Locations**

<b>Location</b>	<b>Symbol</b>	<b>Dates</b>	<b>Purpose</b>
Inside Shared Spectrum offices	ssc_office	10/28/2004, 2/4/2004, 2/9/2004	Test equipment
Outside in Shared Spectrum parking lot	ssc_parking	4/6/2004	Urban location
Riverbend Park	Riverbend Park	4/7/2007	Rural location
Tysons Corner shopping center parking lot	tysons_parking	4/9/2004	Urban location
National Science Foundation (NSF) building roof	NSF_building_roof	4/16/2004	Elevated, urban location
New York City	NYC	8/5/2004	Elevated, urban location
New York City	NYC_convention	8/30/2004, 4/9/2004	Elevated, urban location
National Radio Astronomy Observatory, Green Bank, West Virginia	NRAO	10/4/2004	Very quiet, rural location
Shared Spectrum office roof	ssc_roof	Multiple 12/15/2004- 6/9/2005	Elevated, urban location using a wide variety of frequency lists

### 4. Measurement Reports

This section describes the other reports generated in this project. A subset of the data from six locations was documented in individual reports as listed below. These reports provide both absolute and comparative estimates of the measured spectrum occupancy in a variety of locations.

- “Spectrum Occupancy Measurements, Location 1 of 6: Riverbend Park, Great Falls, Virginia”, Mark A. McHenry, Karl Steadman, Shared Spectrum Company Report, August, 2005.
- “Spectrum Occupancy Measurements, Location 2 of 6: Tyson’s Square Center, Vienna, Virginia, April 9, 2004”, Mark A. McHenry Karl Steadman, Shared Spectrum Company Report, August, 2005.
- “Spectrum Occupancy Measurements, Location 3 of 6: National Science Foundation Building Roof, April 16, 2004, Revision 2”, Mark A. McHenry, Shyam Chunduri, Shared Spectrum Company Report, August, 2005.
- “Spectrum Occupancy Measurements, Location 4 of 6: Republican National Convention, New York City, New York, August 30, 2004 - September 3, 2004, Revision 2”, Mark A. McHenry, Dan McCloskey, George Lane-Roberts, Shared Spectrum Company Report, August, 2005.
- “Spectrum Occupancy Measurements, Location 5 of 6: National Radio Astronomy Observatory (NRAO), Green Bank, West Virginia, October 10 - 11, 2004, Revision 3” Mark A. McHenry Karl Steadman, Shared Spectrum Company Report, August, 2005.
- “Spectrum Occupancy Measurements, Location 6 of 6: Shared Spectrum Building Roof, Vienna, Virginia, December 15-16, 2004”, Mark A. McHenry, Dan McCloskey, Jim Bates, Shared Spectrum Company Report, August, 2005.

These reports are organized into six sections, as follows:

Section 1 Introduction

Section 2 Description of measurement equipment

Section 3 Site and surrounding environment where measurements were taken

Section 4 Frequency lists used for the spectrum occupancy measurements

Section 5 Plots showing measured spectrum occupancy for each band.

Section 6 Conclusions

# NSF Spectrum Occupancy Measurements Project Summary

**Table 2 Summary of Measurements and Data Files**

Date	Location	Frequency Range	Antenna	Frequency List	Plotted (yes/no)	Start Time	End time	File Prefix	Calibration File Name	Start File Number	End File Number	Number of Files	Duration (sec)	Duration (hr)
20040128	ssc_office	66-72 MHz				11:17	12:17			103	2813	2711		
20040128	ssc_office	30-54 MHz				18:11	18:20	nsf		2957	3156	200		
20040128	ssc_office	54-88 MHz				18:32	18:41	nsf		3166	3367	202		
20040204	ssc_office	54-88 MHz	rotating			15:14	16:13	nsf		3673	3780	108		
20040204	ssc_office	88-108 MHz	stat			19:20	20:19	nsf		3782	3911	130		
20040128	ssc_office									3166	3367	202		
20040209	ssc_office	1400-1525 MHz	stat			12:10	13:09			4025	4133	109		
20040406	ssc_parking		rotating			12:58	13:57	nsf		493	587	95		
20040406	ssc_parking		stat			14:24	15:23	nsf		588	696	109		
20040407	Riverbend Park	30-960MHz	rotating	List_B2	yes	11:22	12:22	nsf	Riverbend_Park_calibration_v1.xls	699	794	96	1200	0.3
20040407	Riverbend Park	30-960MHz	stat	List_B2	yes	12:34	13:34	nsf	Riverbend_Park_calibration_v2.xls	795	907	113	3600	1.0
20040407	Riverbend Park	1240-2900MHz	rotating	List_C2	yes	14:00	15:01	nsf	Riverbend_Park_calibration_v3.xls	908	984	77	3660	1.0
20040407	Riverbend Park	1240-2900MHz	stat	List_C2	yes	15:05	15:55	nsf	Riverbend_Park_calibration_v2.xls	985	1056	77	3000	0.8
20040409	tysons_parking	30-960MHz	rotating		yes	10:34	11:33	nsf	Tysons_Corner_calibration_rotating.xls	1065	1162	98	3540	1.0
20040409	tysons_parking	30-960MHz	stat		yes	11:43	12:43	nsf	Tysons_Corner_calibration_stat.xls	1163	1276	114	3600	1.0
20040409	tysons_parking	1240-2900MHz	rotating		yes	12:56	13:55	nsf	Tysons_Corner_calibration_rotating.xls	1277	1353	77	3540	1.0
20040409	tysons_parking	1240-2900MHz	stat		yes	14:02	14:44	nsf	Tysons_Corner_calibration_stat.xls	1354	1412	59	2520	0.7
20040416	NSF_building_roof	30-960MHz		List_B2	yes	9:25	10:26	nsf	NSF_roof_calibration.xls	1414	1527	114	3660	1.0
20040416	NSF_building_roof	30-960MHz		List_B2	yes	10:29	11:29	nsf	NSF_roof_calibration.xls	1528	1641	114	3600	1.0
20040416	NSF_building_roof	1240-2900MHz		List_C2	yes	11:37	12:38	nsf	NSF_roof_calibration.xls	1642	1728	87	3660	1.0
20040416	NSF_building_roof	30-960MHz		List_B2	yes	12:51	13:52	nsf	NSF_roof_calibration.xls	1731	1843	113	3660	1.0
20040416	NSF_building_roof	1240-2900MHz		List_C2	yes	15:54	16:53	nsf	NSF_roof_calibration.xls	1844	1938	95	3540	1.0
20040416	NSF_building_roof	1240-2900MHz		List_C2	yes	17:08	18:07	nsf	NSF_roof_calibration.xls	1939	2015	77	3540	1.0
20040805	NYC	30-960MHz	stat	List_B2	yes	12:24	13:29	nsf_nyc	NYC_calibration_20040805.xls	10	80	71	3900	1.1
20040830	NYC_Convention	0-1GHz	stat	List_D4	yes	11:29	11:45	nsf_listD	NYC_calibration_List_D.xls	1	44	44	960	0.3
20040830	NYC_Convention	1-3GHz	stat	List_D8	yes	11:54	12:09	nsf_listD	NYC_calibration_List_D.xls	45	66	22	900	0.3
20040830	NYC_Convention	30-2900MHz	stat	List_B	yes	14:44	16:06	gen_nyc	NYC_calibration.xls	1	36	36	4920	1.4
20040830	NYC_Convention	30-2900MHz	stat	List_B	yes	16:11	16:47	gen_nyc	NYC_calibration.xls	39	44	6	2160	0.6
20040830	NYC_Convention	138-470MHz	stat	List_A	yes	16:19	16:19	public_nyc	NYC_calibration.xls	100	104	5	60	0.0
20040830	NYC_Convention	30-2900MHz	stat	List_B	yes	16:56	10:26	gen_nyc	NYC_calibration.xls	46	219	174	63000	17.5
20040830	NYC_Convention	138-470MHz	stat	List_A	yes	18:37	18:43	public_nyc	NYC_calibration.xls	1000	1041	42	360	0.1
20040831	NYC_Convention	30-2900MHz	stat	List_B	yes	15:46	20040903	gen_nyc	NYC_calibration.xls	227	724	498	253920	70.5
20040831	NYC_Convention	138-470MHz	stat	List_A	yes	22:03	23:08	public_nyc	NYC_calibration.xls	10000	10409	410	3900	1.1
20040901	NYC_Convention	30-965MHz	stat	List_C	yes	16:45	20:35	nsf_listc	NYC_calibration.xls	7	84	78	13800	3.8
20041004	NRAO	138-470MHz	stat	List_A	yes	23:31	9:06	public_nyc	NRAO_calibration_A.xls	15681	15921	241	34500	9.6
20041004	NRAO	30-2900MHz	stat	List_B	yes	23:33	9:05	gen_nyc	NRAO_calibration_B.xls	392	631	240	34320	9.5
20041215	ssc_roof	30-960MHz	stat		yes	11:58:00	5:48:00	b15_ssc_roof	SSC_roof_calibration_20041215.xls	1	999	999	21000	5.8
20041216	ssc_roof	960-2900MHz	stat		yes	19:36	16:30	bhigh15_ssc_roof	SSC_roof_calibration_20041216.xls	1	925	925	75240	20.9
20041217	ssc_roof	30-960MHz	stat			19:27	20041218	b15_ssc_roof	SSC_roof_calibration_20041217.xls	1	1597	1597	102720	28.5
20041222	ssc_roof	30-2900MHz	stat		yes	8:27	11:47	dynamic_range_ssc_roof	SSC_roof_calibration_20041223.xls	1	224	224	9000	2.5
20041222	ssc_roof	30-2900MHz	stat		yes	12:09	14:12	both_bands_ssc_roof2	SSC_roof_calibration_20041223.xls	226	277	52	9000	2.5
20041223	ssc_roof	30-2900MHz	stat		yes	8:03	10:32	dynamic_range_ssc_roof	SSC_roof_calibration_20041223.xls	280	343	64	9000	2.5
20041223	ssc_roof	30-2900MHz	stat		yes	17:50	2004_1228	both_bands_ssc_roof2	SSC_roof_calibration_20041222.xls	347	3290	2944	532500	147.9
20050117	ssc_roof	30-2900MHz	stat		yes	19:13	9:22	ssc_roof2_ListA	SSC_roof_calibration_20050117.xls	1	3936	3936	569340	158.2
20050215	ssc_roof	1240-2900MHz	stat		yes	12:22	12:10	ssc_roof2_High_Band	SSC_roof_calibration_20050215.xls	1	1171	1171	85680	23.8
20050226	ssc_roof	30-960MHz	stat		yes	19:29	1:35	ssc_roof2_High_Res	SSC_roof_calibration_20050226.xls	1	1288	1288	453960	126.1
20050305	ssc_roof	1990-2110MHz	stat		yes	17:00	19:18	ssc_roof2_AuxTV_Band	SSC_roof_calibration_20050305.xls	1	35612	35612	267480	74.3
20050315	ssc_roof	216-470MHz	stat		yes	11:11	23:59	VHF_band_ssc_roof	SSC_roof_calibration_20050315.xls	1	2100	2100	46080	12.8
20050319	ssc_roof	54-806MHz	stat		yes	16:25	23:59	TV_band_ssc_roof	SSC_roof_calibration_20050319.xls	2	687	686	27240	7.6
20050609	ssc_roof	30-2900MHz	stat		yes	15:52	20050610	ssc_roof2_new	SSC_roof_calibration_20050609.xls	17	817	801	115560	32.1

### 5. Data File Description

This section describes the data files that were collected in this project. This data is available for other researcher's use. Electronic copies of the data provided in this report may be requested from NRNRT by contacting Professor. Gary Minden, University of Kansas, Information and Telecommunication Technology Center, Center for Research, Inc., (email: gminden@ittc.ku.edu; tel: 785-864-4834), or Dr. Mark McHenry, Shared Spectrum Company, (email: mmchenry@sharedspectrum.com; tel: 703-761-2818 x-103)

#### 5.1 Files Collected at Each Location

Separate raw data files were collected for each collection of a frequency list. The file size is 10k to 50 k, depending on the number of frequency bands. The filename consists of a "file prefix" and a file number value that incremented with each spectrum analyzer scan. A measurement consists of hundreds to thousands of files. Table 2 shows the file name and file numbers collected at each location.

The raw data files are included in the project data files. They are organized in directories based on measurement site location and collection date and time.

## 5.2 Calibration

The raw data files are the power levels measured by the spectrum analyzer. The plotted data is the power level at the antenna input. Before plotting, the data was corrected for the RF chain (pre-selector amplifier gain, filter losses, and cable loss) loss. The RF chain loss value versus frequency and versus pre-selector attenuation value was measured using a network analyzer and then stored in files. An example calibration file is shown in Figure 3. Because the RF equipment varied during the measurements, separate calibration files were collected for each measurement. These calibration files are included with the project data files.

Frequency (MHz)	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
30	36.90	34.92	32.71	30.79	28.64	26.74	24.56	22.68	20.81	18.89	16.70	14.81	12.82	10.94	8.76	6.85
35	36.75	34.75	32.55	30.63	28.44	26.54	24.35	22.47	20.57	18.68	16.72	14.69	12.61	10.70	8.54	6.65
40	36.96	34.52	32.38	30.46	28.33	26.43	24.25	22.37	20.47	18.58	16.70	14.72	12.54	10.64	8.39	6.59
45	36.18	34.22	32.01	30.11	28.00	26.10	24.00	22.00	20.00	18.00	16.00	14.00	12.00	10.30	8.14	6.14
50	34.88	32.90	30.69	28.78	26.65	24.75	22.39	20.68	18.81	17.09	14.72	12.83	10.85	8.95	6.79	4.91
55	36.82	34.90	32.74	30.83	28.82	26.91	24.76	22.86	21.05	19.12	16.95	15.04	13.10	11.18	9.06	7.13
60	36.69	34.76	32.60	30.69	28.70	26.80	24.63	22.74	20.94	19.00	17.09	14.93	12.98	11.09	8.91	7.02
65	36.46	34.53	32.62	30.48	28.75	26.59	24.42	22.54	20.75	18.81	16.65	14.73	12.78	10.87	8.70	6.83
70	36.03	34.10	31.93	30.03	28.07	26.19	24.04	22.14	20.14	18.42	16.25	14.35	12.40	10.49	8.34	6.72
75	35.54	33.63	31.49	29.59	27.65	25.77	23.63	21.73	19.96	18.02	15.85	13.95	11.99	10.09	7.97	6.05
80	34.99	33.04	30.88	28.97	27.00	25.08	22.94	21.21	19.24	17.24	15.16	13.23	11.27	9.37	7.22	5.50
85	13.93	12.03	9.93	8.02	6.16	4.27	2.11	0.2					-9.48	-11.38	-13.53	-15.41
110	5.65	3.71	1.57	-0.35	-2.41	-4.33	-6.36	-8.2					-16.58	-19.49	-21.58	-23.98
115	27.69	25.73	23.55	21.55	19.52	17.61	15.44	13.51					3.69	1.81	-0.36	-2.22
120	30.13	28.36	26.29	24.33	22.20	20.20	18.17	16.17	14.32	12.42	10.28	8.41	6.45	4.58	2.36	0.59
125	30.35	28.69	26.65	24.72	22.69	20.83	18.68	17.07	14.89	13.02	10.81	8.98	6.97	5.14	2.99	1.05
130	30.44	28.68	26.60	24.80	22.93	21.01	18.85	17.00	15.07	13.22	11.14	9.20	7.22	5.36	3.24	1.28
135	30.95					21.27	19.08	17.21	15.30	13.45	11.27	9.41	7.45	5.64	3.35	1.54
140	31.52					21.49	19.30	17.45	15.45	13.58	11.40	9.62	7.61	5.72	3.50	1.65
145	31.30	29.40	27.31	25.44	23.23	21.23	19.26	17.35	15.25	13.43	11.24	9.39	7.38	5.55	3.37	1.49
150	30.93	29.16	27.07	25.27	23.06	21.26	19.01	17.20	15.11	13.26	11.07	9.25	7.25	5.41	3.19	1.39
155	29.76	28.06	25.97	24.19	22.01	20.27	17.99	16.18	14.08	12.26	10.07	8.26	6.24	4.40	2.14	0.45
160	28.28	26.53	24.42	22.63	20.46	18.05	16.44	14.62	12.52	10.71	8.52	6.69	4.72	2.90	0.58	-1.18
165	25.42	23.75	21.68	19.93	17.65	15.83	13.64	11.84	9.66	7.88	5.66	3.89	1.86	0.06	-2.20	-3.89
170	21.39	19.75	17.74	16.00	13.78	11.97	9.78	7.99	5.80	4.04	1.85	0.00	-1.93	-3.84	-6.11	-7.79

Figure 3 Example calibration file.

## 5.3 Data File Format

The format of the raw data files is shown in Figure 4, Figure 5, Figure 6 and Figure 7. The file format was changed several times during the project because the hardware was changed during the project (antenna rotator and computer controlled pre-selector).

<u>Data File</u>	<u>Description</u>
54 - 88 MHz Band	File title
501	Number of points in each trace
1	NA
1	NA
04-Feb-2004 16:03:05	Date and time
359.900000	Antenna azimuth in degrees
88000000.000000	Start frequency in Hz
108000000.000000	End frequency in Hz
0.000000	NA
-10.000000	Spectrum analyzer reference level in dBm
10000.000000	Spectrum analyzer video bandwidth in Hz
10.000000	Spectrum analyzer RF attenuation level in dB
-96.10	Power in frequency bin 1 in dBm
-90.24	Power in frequency bin 2 in dBm
-93.19	Power in frequency bin 3 in dBm
-96.28	Power in frequency bin 4 in dBm
...	...
-93.71	Power in frequency bin 500 in dBm
-94.17	Power in frequency bin 501 in dBm
54 - 88 MHz Band	File title
501	Number of points in each trace
1	NA
1	NA
04-Feb-2004 16:03:06	Date and time
359.900000	Antenna azimuth in degrees
108000000.000000	Start frequency in Hz
138000000.000000	End frequency in Hz
0.000000	NA
-10.000000	Spectrum analyzer reference level in dBm
10000.000000	Spectrum analyzer video bandwidth in Hz
10.000000	Spectrum analyzer RF attenuation level in dB
-75.21	Power in frequency bin 1 in dBm
-75.66	Power in frequency bin 2 in dBm
...	...

**Figure 4 Spectrum measurement data file format used in SSC Office, SSC Parking Lot, Riverbend, Tysons, and NSF roof (rotating) measurements.**

<u>Data File</u>	<u>Description</u>
Antenna Stationary	File title
501	Number of points in each trace
1	NA
1	NA
16-Apr-2004 11:37:36	Date and time
1240000000.000000	Start frequency in Hz
1300000000.000000	End frequency in Hz
0.000000	NA
-20.000000	Spectrum analyzer reference level in dBm
10000.000000	Spectrum analyzer video bandwidth in Hz
0.000000	Spectrum analyzer RF attenuation level in dB
-101.06	Power in frequency bin 1 in dBm
-102.95	Power in frequency bin 2 in dBm
-104.57	Power in frequency bin 3 in dBm
...	...
-102.02	Power in frequency bin 500 in dBm
-103.11	Power in frequency bin 501 in dBm
Antenna Stationary	File title
501	Number of points in each trace
1	NA
1	NA
16-Apr-2004 11:37:39	Date and time
1300000000.000000	Start frequency in Hz
1400000000.000000	End frequency in Hz
0.000000	NA
-20.000000	Spectrum analyzer reference level in dBm
10000.000000	Spectrum analyzer video bandwidth in Hz
0.000000	Spectrum analyzer RF attenuation level in dB
-102.14	Power in frequency bin 1 in dBm
-101.59	Power in frequency bin 2 in dBm
...	...

**Figure 5 Spectrum measurement data file format used in SSC Office, SSC Parking Lot, Riverbend, Tysons, and NSF roof (stationary) measurements.**

<u>Data File</u>	<u>Description</u>
NYC List D data	File title
501	Number of points in each trace
1	NA
1	NA
30-Aug-2004 11:59:37	Date and time
1000000000.000000	Start frequency in Hz
1250000000.000000	End frequency in Hz
0.000000	Antenna azimuth in degrees
-20.000000	Spectrum analyzer reference level in dBm
10000.000000	Spectrum analyzer resolution bandwidth in Hz
20.000000	Spectrum analyzer RF attenuation level in dB
-93.07	Power in frequency bin 1 in dBm
-91.48	Power in frequency bin 2 in dBm
-92.34	Power in frequency bin 3 in dBm
-91.56	Power in frequency bin 4 in dBm
-94.28	Power in frequency bin 5 in dBm
-93.16	Power in frequency bin 6 in dBm
-93.01	Power in frequency bin 7 in dBm
-93.83	Power in frequency bin 8 in dBm
-92.46	Power in frequency bin 9 in dBm
...	...
-92.42	Power in frequency bin 500 in dBm
-91.61	Power in frequency bin 501 in dBm
NYC List D data	File title
501	Number of points in each trace
1	NA
1	NA
30-Aug-2004 11:59:42	Date and time
1250000000.000000	Start frequency in Hz
1500000000.000000	End frequency in Hz
0.000000	Antenna azimuth in degrees
-20.000000	Spectrum analyzer reference level in dBm
10000.000000	Spectrum analyzer resolution bandwidth in Hz
20.000000	Spectrum analyzer RF attenuation level in dB
-92.44	Power in frequency bin 1 in dBm
-90.81	Power in frequency bin 2 in dBm
-93.32	
-93.12	
-93.79	
....	

**Figure 6 Spectrum measurement data file format used in New York measurements.**

<u>Data File</u>	<u>Description</u>
ssc_roof Measurements	File title
501	Number of points in each trace
7	Number of frequency bands
1 1 15 4 -1	A, B, C, D, E (see Note A below)
24-Jan-2005 09:53:40	Date and time
54000000.000000	Start frequency in Hz
88000000.000000	End frequency in Hz
10000.000000	Spectrum analyzer resolution bandwidth in Hz
-20.000000	Spectrum analyzer reference level in dBm
10.000000	Spectrum analyzer video bandwidth in kHz
10.000000	Spectrum analyzer RF attenuation level in dB
-80.00	Power in frequency bin 1 in dBm
-81.89	Power in frequency bin 2 in dBm
-82.02	Power in frequency bin 3 in dBm
-77.49	Power in frequency bin 4 in dBm
...	...
-101.71	Power in frequency bin 500 in dBm
-100.64	Power in frequency bin 501 in dBm
ssc_roof Measurements	File title
501	Number of points in each trace
7	Number of frequency bands
1 1 20 4 -1	A, B, C, D, E (see Note A below)
24-Jan-2005 09:53:44	Date and time
174000000.000000	Start frequency in Hz
216000000.000000	End frequency in Hz
10000.000000	Spectrum analyzer resolution bandwidth in Hz
-20.000000	Spectrum analyzer reference level in dBm
10.000000	Spectrum analyzer video bandwidth in kHz
10.000000	Spectrum analyzer RF attenuation level in dB
-92.45	Power in frequency bin 1 in dBm
-92.25	Power in frequency bin 2 in dBm
...	

### Note A

A = SA\_preselect - spectrum preselector on (=1) or off(=0)  
B = pre\_selector\_band (=1 or 2)  
C = pre\_selector\_atten\_dB (=0 to 30 dB)  
D = pre\_selector\_Filter\_A (=1 though =6)  
E = pre\_selector\_Filter\_B(=1 though =6),

**Figure 7 Spectrum measurement data file format used in SSC Roof measurements.**

## 6. Conclusions

This section provides the conclusions of the NSF Spectrum Measurement project.

### 6.1 Measurements Show That There is Significant Spectrum “Whitespace”

The goal of this study was to determine the spectrum occupancy in each band at multiple locations. The bar graphs in Figure 8 and Figure 9 below provide the average of the occupancy in each band and at each location. The average occupancy over all of the locations is 5.2%. The maximum occupancy is 13.1% (New York City) and the minimum occupancy is at the National Radio Astronomy Observatory (1%). These low occupancy levels show that there is significant spectrum for a Dynamic Spectrum Sharing Radio (DSS) to provide service. In rural areas, there is enough unused spectrum for a DSS Radio to provide ten times the capacity of all existing wireless devices together.

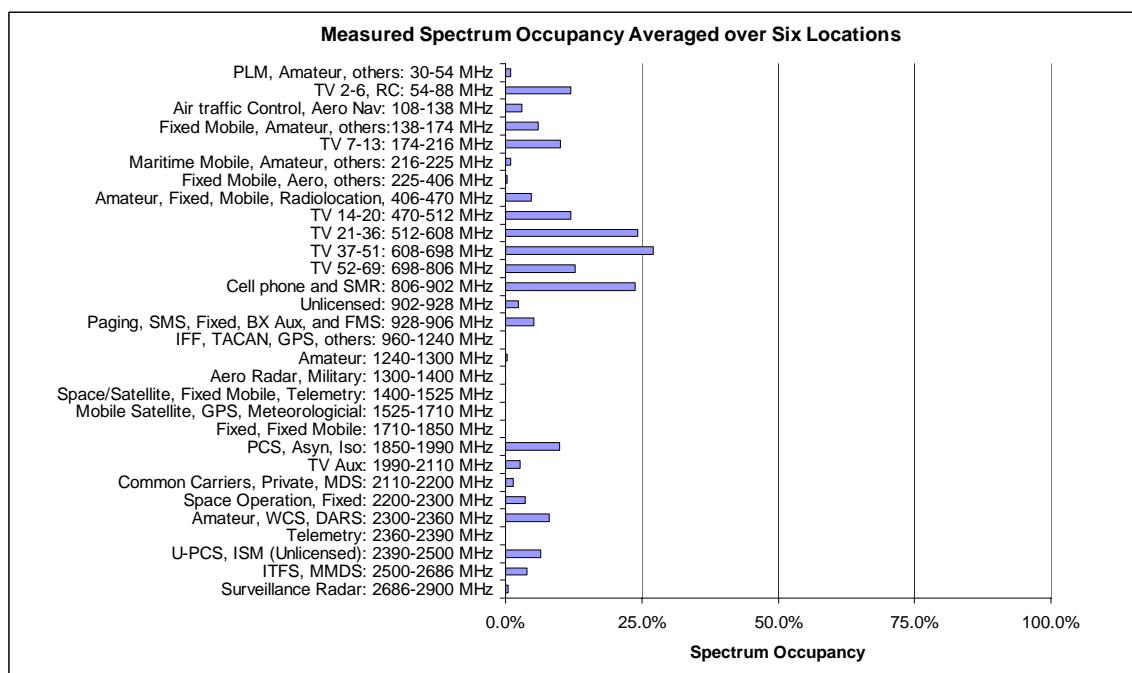
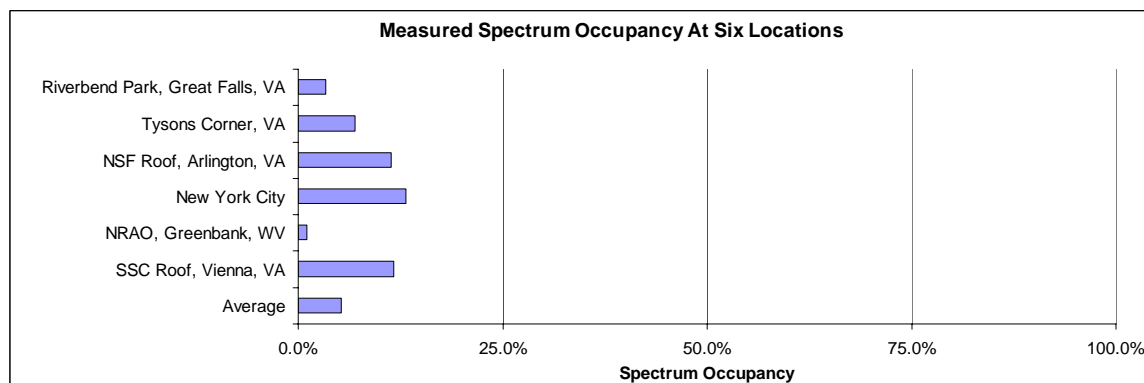


Figure 8 Spectrum occupancy in each band averaged over six locations.



**Figure 9 Spectrum occupancy at each location.**

Table 3 shows a summary of the occupancy from all six locations. Table 4, Table 5, Table 6, Table 7, Table 8, and Table 9 provide the occupancy in each band at each location. The average occupancy over all of the locations is 5.2%. The maximum occupancy is 13.1% (New York City) and the minimum occupancy is at the National Radio Astronomy Observatory (1%).

These low occupancy levels show that there is significant spectrum for a Dynamic Spectrum Sharing Radio (DSS) to provide service. In rural areas, there is enough unused spectrum for a DSS Radio to provide ten times the capacity of all existing wireless devices together.

### **6.2 A Low Agility, Contiguous DSS Radio Waveform Can Provide High Utility**

The detail spectrum occupancy plots show that there is a significant amount of spectrum available in continuous blocks that are 1 MHz and wider. An example is the TV Auxiliary band, where there is large, contiguous spectrum segments not used for hours at a time. This shows that a frequency agile, non-contiguous waveform is not necessary for a DSS Radio. A DSS Radio with a low agility, contiguous waveform will provide high utility.

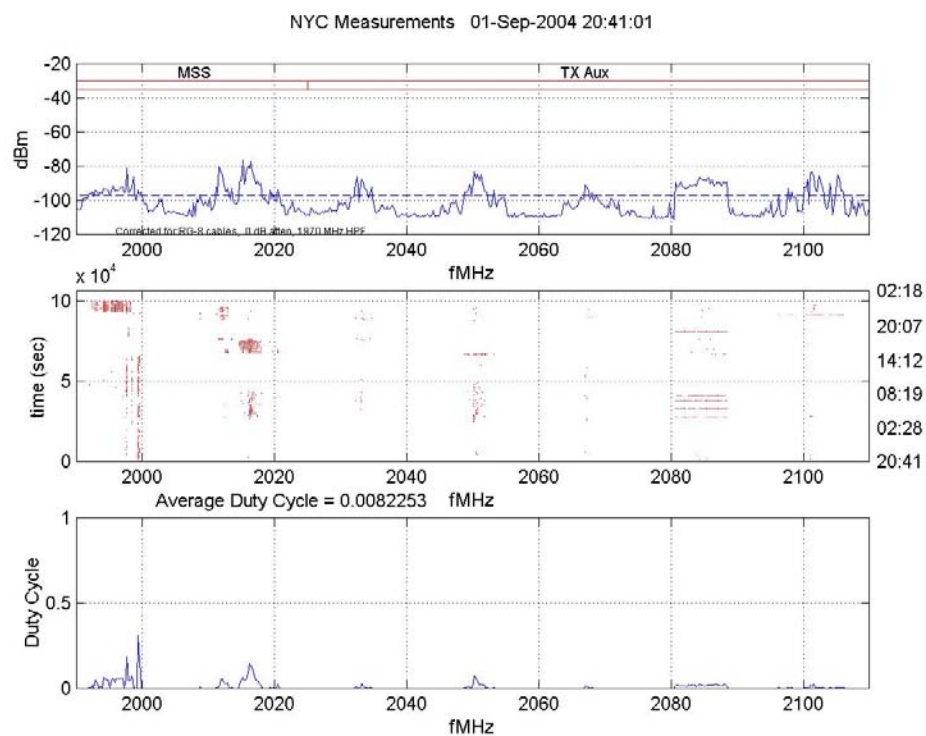


Figure 10 NYC spectrum measurement from September 1 to September 3, 1990 MHz – 2110 MHz

### 6.3 An Extensive Spectrum Occupancy Dataset Is Available for Future Analysis

We have collected an extensive spectrum occupancy data set that is available for others to investigate. In Section 7, we provide several suggested areas for further investigation.

## NSF Spectrum Occupancy Measurements Project Summary

**Table 3 Summary of Spectrum Occupancy in Each Band Measured at Six Locations**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	Riverbend Spectrum Fraction Used	Riverbend Occupied Spectrum (MHz)	Tyson's Spectrum Fraction Used	Tyson's Occupied Spectrum (MHz)	NSF Roof Spectrum Fraction Used	NSF Roof Occupied Spectrum (MHz)	NYC Day 1 Spectrum Fraction Used	NYC Day 2 Spectrum Fraction Used	NYC Avg Spectrum Fraction Used	NYC Occupied Spectrum (MHz)	NRAO Spectrum Fraction Used	NRAO Occupied Spectrum (MHz)	SSC Roof Spectrum Fraction Used	SSC Roof Occupied Spectrum (MHz)	Average Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.03895	0.93	0.00763	0.18	0.00217	0.05	0.04300	0.06250	0.05275	1.27	0.00045	0.01	0.00400	0.10	0.22	0.9%
54	88	34	TV 2-6, RC	0.10593	3.60	0.11799	4.01	0.36654	12.46	0.52830	0.52080	0.52455	17.83	0.11056	3.76	0.10900	3.71	4.07	12.0%
108	138	30	Air traffic Control, Aero Nav	0.00744	0.22	0.02768	0.83	0.04066	1.22	0.05270	0.04030	0.04650	1.40	0.15485	4.65	0.10000	3.00	0.91	3.0%
138	174	36	Fixed Mobile, amateur, others	0.03372	1.21	0.07692	2.77	0.16865	6.07	0.17080	0.16980	0.17030	6.13	0.02745	0.99	0.07300	2.63	2.15	6.0%
174	216	42	TV 7-13	0.10339	4.34	0.11652	4.89	0.18890	7.93	0.77730	0.77950	0.77840	32.69	0.00220	0.09	0.18100	7.60	4.26	10.1%
216	225	9	Maritime Mobile, Amateur, others	0.00486	0.04	0.00842	0.08	0.01129	0.10	0.05860	0.05950	0.05905	0.53	0.00556	0.05	0.02300	0.21	0.08	0.9%
225	406	181	Fixed Mobile, Aero, others	0.00002	0.00	0.00371	0.67	0.00576	1.04	0.00530	0.00370	0.00450	0.81	0.01842	3.33	0.01300	2.35	0.68	0.4%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.02745	1.76	0.07243	4.64	0.10469	6.70	0.16610	0.14750	0.15680	10.04	0.00379	0.24	0.08100	5.18	3.07	4.8%
470	512	42	TV 14-20	0.13313	5.59	0.12160	5.11	0.29794	12.51	0.21140	0.21000	0.21070	8.85	0.00379	0.16	0.15700	6.59	5.00	11.9%
512	608	96	TV 21-36	0.26616	25.55	0.32736	31.43	0.49667	47.68	0.35520	0.34270	0.34895	33.50	0.04283	4.11	0.36400	34.94	23.33	24.3%
608	698	90	TV 37-51	0.23484	21.14	0.39980	35.98	0.47044	42.34	0.46160	0.46090	0.46125	41.51	0.00156	0.14	0.51300	46.17	24.35	27.1%
698	806	108	TV 52-69	0.07627	8.24	0.17337	18.72	0.20048	21.65	0.29580	0.30790	0.30185	32.60	0.00113	0.12	0.31300	33.80	13.79	12.8%
806	902	96	Cell phone and SMR	0.14260	13.69	0.41188	39.54	0.46398	44.54	0.46190	0.46450	0.46320	44.47	0.00017	0.02	0.40000	38.40	22.77	23.7%
902	928	26	Unlicensed	0.00000	0.00	0.03915	1.02	0.08687	2.26	0.22270	0.23460	0.22865	5.94	0.00004	0.00	0.01100	0.29	0.63	2.4%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.03460	1.11	0.06708	2.15	0.10438	3.34	0.23640	0.24370	0.24005	7.68	0.02459	0.79	0.10000	3.20	1.68	5.2%
960	1240	280	IFF, TACAN, GPS, others							0.03560	0.04080	0.03820	10.70		0.00	0.00000	0.00	0.01	0.0%
1240	1300	60	Amateur	0.00139	0.08	0.00335	0.20	0.01509	0.91	0.00030	0.00010	0.00020	0.01	0.00012	0.01	0.00000	0.00	0.20	0.3%
1300	1400	100	Aero Radar, military	0.00022	0.02	0.00562	0.56	0.00718	0.72	0.02160	0.00130	0.01145	1.15	0.00000	0.00	0.00000	0.00	0.22	0.2%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00000	0.00	0.00000	0.00	0.00083	0.10	0.01520	0.00050	0.00785	0.98	0.00000	0.00	0.00000	0.00	0.02	0.0%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological	0.00000	0.00	0.00000	0.00	0.00220	0.41	0.00240	0.00130	0.00185	0.34	0.00082	0.15	0.00000	0.00	0.07	0.0%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00	0.00000	0.00	0.00137	0.19	0.02350	0.02540	0.02445	3.42	0.00000	0.00	0.00000	0.00	0.04	0.0%
1850	1990	140	PCS, Asyn, Iso	0.00044	0.06	0.12690	17.77	0.27102	37.94	0.33090	0.34430	0.33760	47.26	0.00001	0.00	0.19300	27.02	13.85	9.9%
1990	2110	120	TV Aux	0.00000	0.00	0.00000	0.00	0.00005	0.01	0.01910	0.00820	0.01365	1.64	0.00009	0.01	0.15900	19.08	3.18	2.7%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00000	0.00	0.00000	0.00	0.00397	0.36	0.01820	0.01900	0.01860	1.67	0.00353	0.32	0.08100	7.29	1.28	1.4%
2200	2300	100	Space Operation, Fixed	0.00000	0.00	0.00000	0.00	0.00021	0.02	0.05270	0.06180	0.05725	5.73	0.00000	0.00	0.21400	21.40	3.58	3.6%
2300	2360	60	Amateur, WCS, DARS	0.00000	0.00	0.12693	7.62	0.17754	10.65	0.20220	0.20530	0.20375	12.23	0.10521	6.31	0.17300	10.38	4.83	8.0%
2360	2390	30	Telemetry	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.06200	0.06420	0.06310	1.89	0.00004	0.00	0.00000	0.00	0.01	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.00022	0.02	0.00074	0.08	0.12461	13.71	0.13470	0.15510	0.14490	15.94	0.00007	0.01	0.25700	28.27	7.04	6.4%
2500	2686	186	ITFS, MMDS	0.00000	0.00	0.00000	0.00	0.07046	13.10	0.10430	0.10420	0.10425	19.39	0.00137	0.26	0.16100	29.95	7.19	3.9%
2686	2900	214	Surveillance Radar	0.00000	0.00	0.00000	0.00	0.02123	4.54	0.02860	0.03090	0.02975	6.37	0.00288	0.62	0.00700	1.50	1.01	0.5%
Total		2850			87.62		178.24		292.57				373.97		26.14		333.06	149.52	
Total Available Spectrum					2570		2570		2570				2850		2570		2850	2850	
Average Spectrum Use (%)					3.4%		6.9%		11.4%				13.1%		1.0%		11.7%	5.2%	

**Table 4 Spectrum Occupancy in Each Band Measured at Riverbend Park**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	Spectrum Fraction Used	Riverbend Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.03895	0.93	3.9%
54	88	34	TV 2-6, RC	0.10593	3.60	10.6%
108	138	30	Air traffic Control, Aero Nav	0.00744	0.22	0.7%
138	174	36	Fixed Mobile, amateur, others	0.03372	1.21	3.4%
174	216	42	TV 7-13	0.10339	4.34	10.3%
216	225	9	Maritime Mobile, Amateur, others	0.00486	0.04	0.5%
225	406	181	Fixed Mobile, Aero, others	0.00002	0.00	0.0%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.02745	1.76	2.7%
470	512	42	TV 14-20	0.13313	5.59	13.3%
512	608	96	TV 21-36	0.26616	25.55	26.6%
608	698	90	TV 37-51	0.23484	21.14	23.5%
698	806	108	TV 52-69	0.07627	8.24	7.6%
806	902	96	Cell phone and SMR	0.14260	13.69	14.3%
902	928	26	Unlicensed	0.00000	0.00	0.0%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.03460	1.11	3.5%
960	1240	280	IFF, TACAN, GPS, others	0.00000	0.00	0.0%
1240	1300	60	Amateur	0.00139	0.08	0.1%
1300	1400	100	Aero Radar, military	0.00022	0.02	0.0%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00000	0.00	0.0%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological			
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.00044	0.06	0.0%
1990	2110	120	TV Aux	0.00000	0.00	0.0%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00000	0.00	0.0%
2200	2300	100	Space Operation, Fixed	0.00000	0.00	0.0%
2300	2360	60	Amateur, WCS, DARS	0.00000	0.00	0.0%
2360	2390	30	Telemetry	0.00000	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.00022	0.02	0.0%
2500	2686	186	ITFS, MMDS	0.00000	0.00	0.0%
2686	2900	214	Surveillance Radar	0.00000	0.00	0.0%
Total		2850			87.62	
Total Available Spectrum					2570	
Average Spectrum Use (%)					3.4%	

**Table 5 Spectrum Occupancy in Each Band Measured at Tysons Square Center**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	Tysons Spectrum Fraction Used	Tysons Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.00763	0.18	0.8%
54	88	34	TV 2 -6, RC	0.11799	4.01	11.8%
108	138	30	Air traffic Control, Aero Nav	0.02768	0.83	2.8%
138	174	36	Fixed Mobile, amateur, others	0.07692	2.77	7.7%
174	216	42	TV 7-13	0.11652	4.89	11.7%
216	225	9	Maritime Mobile, Amateur, others	0.00842	0.08	0.8%
225	406	181	Fixed Mobile, Aero, others	0.00371	0.67	0.4%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.07243	4.64	7.2%
470	512	42	TV 14-20	0.12160	5.11	12.2%
512	608	96	TV 21-36	0.32736	31.43	32.7%
608	698	90	TV 37-51	0.39980	35.98	40.0%
698	806	108	TV 52-69	0.17337	18.72	17.3%
806	902	96	Cell phone and SMR	0.41188	39.54	41.2%
902	928	26	Unlicensed	0.03915	1.02	3.9%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.06708	2.15	6.7%
960	1240	280	IFF, TACAN, GPS, others			
1240	1300	60	Amateur	0.00335	0.20	0.3%
1300	1400	100	Aero Radar, military	0.00562	0.56	0.6%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00000	0.00	0.0%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological	0.00000	0.00	0.0%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.12690	17.77	12.7%
1990	2110	120	TV Aux	0.00000	0.00	0.0%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00000	0.00	0.0%
2200	2300	100	Space Operation, Fixed	0.00000	0.00	0.0%
2300	2360	60	Amateur, WCS, DARS	0.12693	7.62	12.7%
2360	2390	30	Telemetry	0.00000	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.00074	0.08	0.1%
2500	2686	186	ITFS, MMDS	0.00000	0.00	0.0%
2686	2900	214	Surveillance Radar	0.00000	0.00	0.0%
Total		2850			178.24	
Total Available Spectrum					2570	
Average Spectrum Use (%)					6.9%	

**Table 6 Spectrum Occupancy in Each Band Measured at NSF Building Roof**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NSF Roof Spectrum Fraction Used	NSF Roof Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.00217	0.05	0.2%
54	88	34	TV 2 -6, RC	0.36654	12.46	36.7%
108	138	30	Air traffic Control, Aero Nav	0.04066	1.22	4.1%
138	174	36	Fixed Mobile, amateur, others	0.16865	6.07	16.9%
174	216	42	TV 7-13	0.18890	7.93	18.9%
216	225	9	Maritime Mobile, Amateur, others	0.01129	0.10	1.1%
225	406	181	Fixed Mobile, Aero, others	0.00576	1.04	0.6%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.10469	6.70	10.5%
470	512	42	TV 14-20	0.29794	12.51	29.8%
512	608	96	TV 21-36	0.49667	47.68	49.7%
608	698	90	TV 37-51	0.47044	42.34	47.0%
698	806	108	TV 52-69	0.20048	21.65	20.0%
806	902	96	Cell phone and SMR	0.46398	44.54	46.4%
902	928	26	Unlicensed	0.08687	2.26	8.7%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.10438	3.34	10.4%
960	1240	280	IFF, TACAN, GPS, others			
1240	1300	60	Amateur	0.01509	0.91	1.5%
1300	1400	100	Aero Radar, military	0.00718	0.72	0.7%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00083	0.10	0.1%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological	0.00220	0.41	0.2%
1710	1850	140	Fixed, Fixed Mobile	0.00137	0.19	0.1%
1850	1990	140	PCS, Asyn, Iso	0.27102	37.94	27.1%
1990	2110	120	TV Aux	0.00005	0.01	0.0%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00397	0.36	0.4%
2200	2300	100	Space Operation, Fixed	0.00021	0.02	0.0%
2300	2360	60	Amateur, WCS, DARS	0.17754	10.65	17.8%
2360	2390	30	Telemetry	0.00000	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.12461	13.71	12.5%
2500	2686	186	ITFS, MMDS	0.07046	13.10	7.0%
2686	2900	214	Surveillance Radar	0.02123	4.54	2.1%
Total		2850			292.57	
Total Available Spectrum					2570	
Average Spectrum Use (%)					11.4%	

## NSF Spectrum Occupancy Measurements Project Summary

**Table 7 Spectrum Occupancy in Each Band Measured at New York City**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NYC Day 1 Spectrum Fraction Used	NYC Day 2 Spectrum Fraction Used	NYC Avg Spectrum Fraction Used	NYC Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.04300	0.06250	0.05275	1.27	5.3%
54	88	34	TV 2 -6, RC	0.52830	0.52080	0.52455	17.83	52.5%
108	138	30	Air traffic Control, Aero Nav	0.05270	0.04030	0.04650	1.40	4.7%
138	174	36	Fixed Mobile, amateur, others	0.17080	0.16980	0.17030	6.13	17.0%
174	216	42	TV 7-13	0.77730	0.77950	0.77840	32.69	77.8%
216	225	9	Maritime Mobile, Amateur, others	0.05860	0.05950	0.05905	0.53	5.9%
225	406	181	Fixed Mobile, Aero, others	0.00530	0.00370	0.00450	0.81	0.5%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.16610	0.14750	0.15680	10.04	15.7%
470	512	42	TV 14-20	0.21140	0.21000	0.21070	8.85	21.1%
512	608	96	TV 21-36	0.35520	0.34270	0.34895	33.50	34.9%
608	698	90	TV 37-51	0.46160	0.46090	0.46125	41.51	46.1%
698	806	108	TV 52-69	0.29580	0.30790	0.30185	32.60	30.2%
806	902	96	Cell phone and SMR	0.46190	0.46450	0.46320	44.47	46.3%
902	928	26	Unlicensed	0.22270	0.23460	0.22865	5.94	22.9%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.23640	0.24370	0.24005	7.68	24.0%
960	1240	280	IFF, TACAN, GPS, others	0.03560	0.04080	0.03820	10.70	3.8%
1240	1300	60	Amateur	0.00030	0.00010	0.00020	0.01	0.0%
1300	1400	100	Aero Radar, military	0.02160	0.00130	0.01145	1.15	1.1%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.01520	0.00050	0.00785	0.98	0.8%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological	0.00240	0.00130	0.00185	0.34	0.2%
1710	1850	140	Fixed, Fixed Mobile	0.02350	0.02540	0.02445	3.42	2.4%
1850	1990	140	PCS, Asyn, Iso	0.33090	0.34430	0.33760	47.26	33.8%
1990	2110	120	TV Aux	0.01910	0.00820	0.01365	1.64	1.4%
2110	2200	90	Common Carriers, Private Companies, MDS	0.01820	0.01900	0.01860	1.67	1.9%
2200	2300	100	Space Operation, Fixed	0.05270	0.06180	0.05725	5.73	5.7%
2300	2360	60	Amateur, WCS, DARS	0.20220	0.20530	0.20375	12.23	20.4%
2360	2390	30	Telemetry	0.06200	0.06420	0.06310	1.89	6.3%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.13470	0.15510	0.14490	15.94	14.5%
2500	2686	186	ITFS, MMDS	0.10430	0.10420	0.10425	19.39	10.4%
2686	2900	214	Surveillance Radar	0.02860	0.03090	0.02975	6.37	3.0%
Total		2850		0.0000	0.0000	0.0000	373.97	
Total Available Spectrum							2850	
Average Spectrum Use (%)							13.1%	

**Table 8 Spectrum Occupancy in Each Band Measured at National Radio Astronomy Observatory**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NRAO Spectrum Fraction Used	NRAO Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.00045	0.01	0.0%
54	88	34	TV 2 -6, RC	0.11056	3.76	11.1%
108	138	30	Air traffic Control, Aero Nav	0.15485	4.65	15.5%
138	174	36	Fixed Mobile, amateur, others	0.02745	0.99	2.7%
174	216	42	TV 7-13	0.00220	0.09	0.2%
216	225	9	Maritime Mobile, Amateur, others	0.00556	0.05	0.6%
225	406	181	Fixed Mobile, Aero, others	0.01842	3.33	1.8%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.00379	0.24	0.4%
470	512	42	TV 14-20	0.00379	0.16	0.4%
512	608	96	TV 21-36	0.04283	4.11	4.3%
608	698	90	TV 37-51	0.00156	0.14	0.2%
698	806	108	TV 52-69	0.00113	0.12	0.1%
806	902	96	Cell phone and SMR	0.00017	0.02	0.0%
902	928	26	Unlicensed	0.00004	0.00	0.0%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.02459	0.79	2.5%
960	1240	280	IFF, TACAN, GPS, others	0.00000	0.00	0.0%
1240	1300	60	Amateur	0.00012	0.01	0.0%
1300	1400	100	Aero Radar, military	0.00000	0.00	0.0%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00000	0.00	0.0%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological	0.00082	0.15	0.1%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.00001	0.00	0.0%
1990	2110	120	TV Aux	0.00009	0.01	0.0%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00353	0.32	0.4%
2200	2300	100	Space Operation, Fixed	0.00000	0.00	0.0%
2300	2360	60	Amateur, WCS, DARS	0.10521	6.31	10.5%
2360	2390	30	Telemetry	0.00004	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.00007	0.01	0.0%
2500	2686	186	ITFS, MMDS	0.00137	0.26	0.1%
2686	2900	214	Surveillance Radar	0.00288	0.62	0.3%
Total		2850			26.14	
Total Available Spectrum					2570	
Average Spectrum Use (%)					1.0%	

**Table 9 Spectrum Occupancy in Each Band Measured at Shared Spectrum Company Building Roof**

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	SSC Roof Spectrum Fraction Used	SSC Roof Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.00400	0.10	0.4%
54	88	34	TV 2 -6, RC	0.10900	3.71	10.9%
108	138	30	Air traffic Control, Aero Nav	0.10000	3.00	10.0%
138	174	36	Fixed Mobile, amateur, others	0.07300	2.63	7.3%
174	216	42	TV 7-13	0.18100	7.60	18.1%
216	225	9	Maritime Mobile, Amateur, others	0.02300	0.21	2.3%
225	406	181	Fixed Mobile, Aero, others	0.01300	2.35	1.3%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.08100	5.18	8.1%
470	512	42	TV 14-20	0.15700	6.59	15.7%
512	608	96	TV 21-36	0.36400	34.94	36.4%
608	698	90	TV 37-51	0.51300	46.17	51.3%
698	806	108	TV 52-69	0.31300	33.80	31.3%
806	902	96	Cell phone and SMR	0.40000	38.40	40.0%
902	928	26	Unlicensed	0.01100	0.29	1.1%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.10000	3.20	10.0%
960	1240	280	IFF, TACAN, GPS, others	0.00000	0.00	0.0%
1240	1300	60	Amateur	0.00000	0.00	0.0%
1300	1400	100	Aero Radar, military	0.00000	0.00	0.0%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00000	0.00	0.0%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorological	0.00000	0.00	0.0%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.19300	27.02	19.3%
1990	2110	120	TV Aux	0.15900	19.08	15.9%
2110	2200	90	Common Carriers, Private Companies, MDS	0.08100	7.29	8.1%
2200	2300	100	Space Operation, Fixed	0.21400	21.40	21.4%
2300	2360	60	Amateur, WCS, DARS	0.17300	10.38	17.3%
2360	2390	30	Telemetry	0.00000	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.25700	28.27	25.7%
2500	2686	186	ITFS, MMDS	0.16100	29.95	16.1%
2686	2900	214	Surveillance Radar	0.00700	1.50	0.7%
Total		2850			333.06	
Total Available Spectrum					2850	
Average Spectrum Use (%)					11.7%	

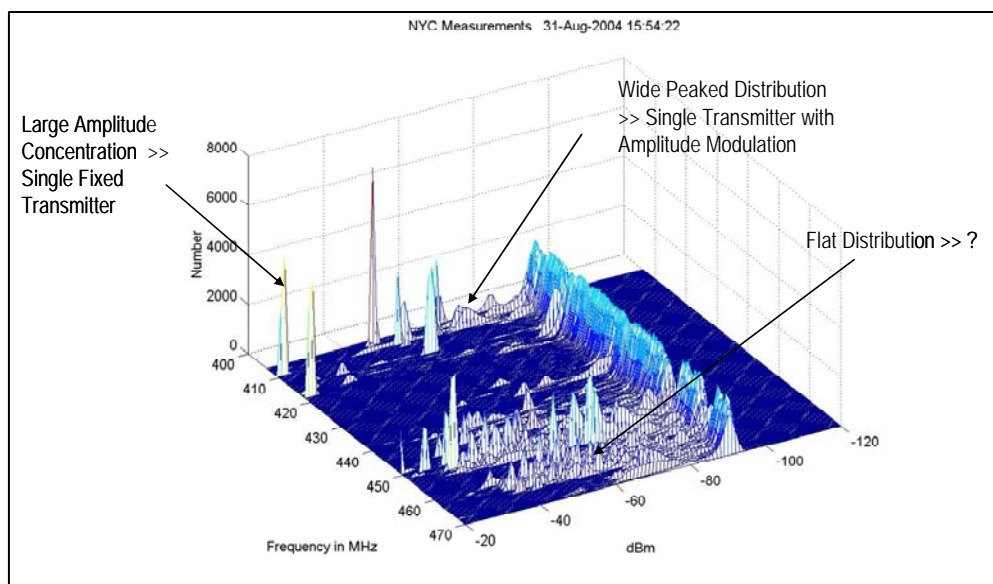
### 7. Suggested Follow-On Research

The following are suggested follow-on research activities related to this project.

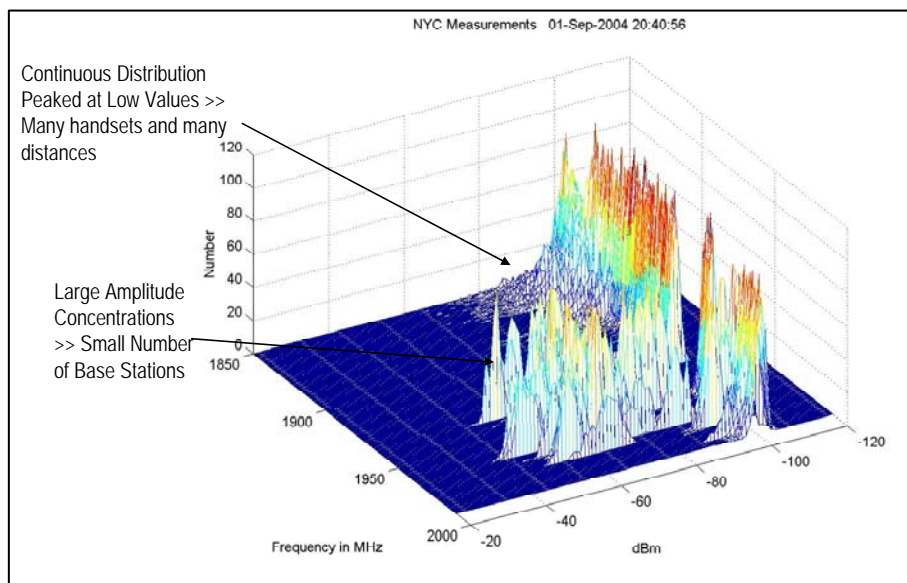
#### 7.1 Parameter Extraction

We proposed to extend the analysis of the data to include the spectrum gaps statistics, the transmitter mobility and number (using the amplitude probability distribution), the signal bandwidths, and other parameters. It is critical for frequency agile and cognitive radios to be able to know what transceiver types actually use spectrum and how they are operated.

We propose to develop the amplitude histogram method that is able to distinguish between different transmitter configurations (number of transmitters, mobility, etc). An example is shown in Figure 11 (Public Safety band) and Figure 12 (PCS band), where the amplitude histograms in the two bands are seen to be very different. Using the amplitude histogram and other analysis methods, we propose to determine the above transmitter parameters in all bands from 30 MHz to 3,000 MHz.



**Figure 11 Amplitude Histogram of Public Safety Band**



**Figure 12 Amplitude Histogram of PCS Band**

### 7.2 More Measurement Locations

The six measurement sites examined in the present NSF study do not include several scenarios (suburban, military, airborne indoor, mobile, etc) and most measurements were conducted over a limited time period. The measurement were conducted at a single locations and don't address the spatial size of spectrum holes.

Ten to twenty additional measurements at different more locations would be helpful to arrive at a broader set of spectrum use conclusions.

### 7.3 Analyze Why Signals Were Not Detected

An analysis needs to be made of the FCC/NTIA rules to identify the radio astronomy bands, passive remote sensing bands, weak signal satellite bands, and other "special" bands where low occupancy is expected. These bands are handled separately from the other bands so that those occupancy measurements are focused on spectrum access issues.

Further investigation of the presumed transmitter characteristics (transmit power level, antenna height, antenna gain pattern, bandwidth, transmit duty cycle, etc) in each band needs to understand what detection distance the spectrum measurement system has against these transmitters. This will provide more insight into the lack of detections in some bands.